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FLUE GAS DESULURIZATION: ANSWERS TO BASIC QUESTIONS

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The purpose of this publication is to provide a better understanding of flue gas desulfurization and to answer questions concerning its applicability, cost, effectiveness, and operation. In the next 10 years, the principal alternative to the combustion of low-sulfur fuels will be the use of flue gas desulfurization (FGD) systems. Such systems can be used in conjunction with all types of fuels but they are particularly appropriate for cleaning gases from the combustion of medium-to-high-sulfur coals, which constitute the largest segment of the nation's fuel reserves. A recent opinion of the U. S. Court of Appeals, however, upheld EPA's new-source performance standard for coal fired steam generators of power plant size. In so doing, the Court found that FGD technology has been adequately demonstrated and that the promulgated standards are achievable.

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Answers to Basic Questions

Emission Standards and Engineering Division

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FLUE GAS DESULFURIZATION
Answers to Basic Questions

INTRODUCTION

In the late 1960's, many state and local jurisdictions enacted regulations to curb SO_2 emissions from coal- and oil-burning power plants. The effect of such regulations was a trend toward the use of low-sulfur oil and coal, and, where possible, of the cleanest fuel, natural gas.

With the Clean Air Act of 1970, limits for SO_2 emissions from fuel-burning sources became more widespread as state plans were adopted to achieve national ambient air quality standards. At the Federal level, new-source performance standards were enacted to limit SO_2 emissions from new steam generators of power plant size. Because of shortages of natural gas and of low-sulfur coal and oil, these limitations cannot be met solely by switching to low-sulfur fuels. It is apparent that coal of medium-to-high sulfur content will have to be burned in increasing quantities by power plants to meet growth requirements and to safeguard an adequate supply of clean fuels for residential, commercial, and industrial use.

The burning of such sulfur-bearing fuels in steam-electric power plants causes appreciable SO_2 air pollution. Generation of electricity in 1970 produced about 20 million tons of SO_2, which was approximately 55 percent of the man-made SO_2 emissions to the nation's atmosphere in 1970. If not controlled, annual SO_2 emissions from power plants could rise to as high as 80 million tons in the year 2000.

In the next 10 years, the principal alternative to the combustion of low-sulfur fuels will be the use of flue gas desulfurization (FGD) systems. Such systems can be used in conjunction with all types of fuels but they are particularly

appropriate for cleaning gases from the combustion of medium-to-high-sulfur coals, which constitute the largest segment of the nation's fuel reserves. The power industry, with some exceptions, has been slow to install FGD systems, maintaining that their effectiveness and applicability have not been proved. This contention has been the principal basis on which standards have been challenged in the courts. A recent opinion of the U.S. Court of Appeals, however, upheld EPA's new-source performance standard for coal-fired steam generators of power plant size. In so doing, the Court found that FGD technology has been adequately demonstrated and that the promulgated standards are achievable.

The purpose of this publication is to provide a better understanding of flue gas desulfurization and to answer questions raised throughout the country concerning its applicability, cost, effectiveness, and operation.

More detailed technical discussions are available in such publications as the Federal interagency (SOCTAP) report, Projected Utilization of Stack Gas Cleaning Systems by Steam-Electric Plants (APTD-1569). Copies of the latter report are available from:

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22151
Price $4.85

Further publications on this subject are listed in "Air Pollution Technical Publications of the U.S. Environmental Protection Agency," which is available, along with the publications, from:

Air Pollution Technical Information Center
Research Triangle Park, North Carolina 27711

FLUE GAS DESULFURIZATION

Answers to Basic Questions

Q. What is a flue gas desulfurization (FGD) system?

A. FGD systems selectively remove sulfur dioxide (SO_2) from gas streams through physical and/or chemical action. Most present-day FGD systems use wet scrubbers as the SO_2 removal device. Alkaline materials in the aqueous media react chemically with SO_2 to form salts, primarily sulfites and sulfates.

Q. Why is flue gas desulfurization important?

A. FGD systems provide an immediate, proved method for controlling SO_2 emissions from the burning of high-sulfur coal, which is the nation's most abundant natural fuel resource. Oil and natural gas are in short supply, coal gasification is still under development, and alternative energy sources offer only long-range solutions. Hence, flue gas desulfurization is the only readily available alternative to the use of low-sulfur fuels, which are scarce, costly, and often available only from foreign sources.

Q. Has the Clean Air Act of 1970 imposed hardships on the power generating industry in terms of time required to develop, finance, and install FGD systems?

A. While the widespread adoption of regulations by states under the 1970 Act has required appreciably increased pollution control action by utilities, the need to control SO_2 did not come as a surprise to anyone. Projections made by the power industry (1964, 1966, and 1970) have indicated a continuing and increasing dependency on coal-generated electricity.

Q. Have electric utilities in the United States had much experience with FGD systems?

A. Pilot plant studies were conducted over 20 years ago at Tennessee Valley Authority plants and have been conducted more recently by Detroit Edison and Wisconsin Electric. Operation of full-scale FGD systems was initiated in 1967 and 1968 by the Union Electric Company at a station in St. Louis, Missouri, and by the Kansas Power and Light Company (KPL) at its Lawrence, Kansas, station. Both of these companies installed limestone scrubbing systems on steam electric generators of greater than 100-megawatt capacity. KPL, and the designers of the system, have incorporated many improvements into the Lawrence station and most of the process problems have been solved. During 1972 and 1973, several additional systems have begun operation. The attached table lists 37 FGD systems that either have been installed or ordered in the United States. They represent a total of about 14,000 megawatts, or about 9 percent of the current U.S. coal-fired electricity-generating capacity.

Q. What other countries besides the United States have been investigating flue gas desulfurization?

A. The first FGD systems were operated in England prior to World War II and some of these are still in operation. More recently, pilot and prototype installations have been operated in Japan and in Sweden and other European countries. The greatest effort has been in Japan, where successful systems are in operation and more are being installed. A lime system has been successfully used in Sweden since 1969 and has achieved high SO_2-removal efficiency together with reliable operation.

Q. What FGD methods are available?

A. Many processes are available, but only four are considered sufficiently developed to make a potentially significant contribution to the control of SO_2 from power plants within the next 5 years: wet lime/limestone scrubbing; magnesium oxide scrubbing with regeneration; catalytic oxidation; and sodium sulfite scrubbing with regeneration. Most scrubbers that have been installed in the United States and abroad have utilized lime or limestone base slurries that react with SO_2 in stack gases to form manageable residues (slurries).

Q. **Is the technology of FGD more complex than that of most industrial chemical processes?**

A. No. FGD systems employ relatively simple process operations requiring far fewer interrelationships than most chemical processes. They include some of the same unit operations that have been used for years in the chemical industry. Problems that have been encountered in the application of FGD systems to power plants are similar to problems routinely solved by the chemical industry.

Q. **How much of the sulfur dioxide in flue gases can be removed with available FGD systems?**

A. Most of the systems being installed in the United States and abroad are designed to achieve 70 to 90 percent or greater SO_2 removal. Though almost any efficiency can be achieved, economics dictates a cutoff. Reasonable SO_2-removal efficiencies of the four developed FGD processes are: 80 to 90 percent for wet lime/limestone scrubbing; 90 percent for magnesium oxide scrubbing; 85 to 90 percent for catalytic oxidation; and 90 percent for regenerable sodium sulfite scrubbing. The above efficiencies have been achieved on a long-term basis at the Mitsui Aluminum plant near Omuta, Japan, and at the Japan Synthetic Rubber plant near Chiba, Japan, with the lime and regenerable sodium sulfite processes, respectively. An efficiency of 90 percent has been achieved with a prototype magnesium oxide system at Boston Edison's Mystic plant (Massachusetts).

Q. **What is the cost of installing and operating an FGD system?**

A. Capital costs for new or retrofit installations generally range from $30 to $65 per kilowatt as compared with the capital cost of a coal-fired steam electric plant of approximately $250 per kilowatt. Capital costs for retrofitting systems to existing generating plants in most cases are expected to be in the range of $45 to $65 per kilowatt. For some retrofitted plants, installation costs have been estimated as high as $80 per kilowatt or more. Some contractor estimates are: $63 for TVA (Alabama); $27 for Northern States Power (Minnesota); $40 for Kansas City Power and Light (Missouri); and $39 for Boston Edison (Massachusetts).

The estimated annual costs for FGD range from 1.2 to 3.2 mills per kilowatt-hour, with a mean of about 2.0

mills per kilowatt-hour. By comparison, the average national consumer cost for power is about 18 mills per kilowatt-hour. Assuming FGD costs are passed on, consumer rates for electricity would increase by about 11 percent for that portion of the utility system for which FGD is required. Few utilities will be required to equip their entire network of steam generators with FGD systems.

Q. Why is the cost of retrofitting existing plants greater than the cost of installing FGD systems on new plants?

A. In general, it is more expensive to retrofit FGD systems than to include them in new construction because of limited space at existing sites and the need to move existing facilities (railroad sidings, tanks, etc.) to install extraordinarily strong footings and other ancillary equipment. Some utilities have reported retrofit costs in excess of $100 per kilowatt. These generally represent very difficult installations and should be considered atypical.

Q. Do rate structures set by public utility commissions affect the installation of FGD systems?

A. Besides installing FGD systems, utilities can meet SO_2 standards by converting coal-fired plants to low-sulfur oil or by securing low-sulfur coal. To many utilities, low-sulfur fuel alternatives appear more attractive than FGD systems because they involve relatively small capital investments and shift a potential capital cost to an operating cost. In a number of states, utilities are now able to pass on to the consumer most of the incremental operating costs of higher priced fuels by means of "fuel adjustment" provisions. The fuel adjustment charges may be passed directly to the consumer via the monthly bill without further action by the regulatory commission.

On the other hand, increases in generating costs resulting from the acquisition of capital equipment and the higher operating costs of FGD systems usually can be compensated for only by rate increases that require action by utility commissions. Not only do utilities have to wait for this compensation until the regulatory commissions act, but they sometimes have to "absorb" a portion of the additional costs. Presently, many commissions treat capital expenditures and operating costs incurred for pollution abatement devices in the same manner.

Recent legislation in some jurisdictions provides incentives for the use of air pollution control equipment by allowing for automatic rate adjustments that compensate for pollution control equipment as well as for the cost of fuel changes.

Q. **Has the utility industry supported or conducted research on air pollution control in general and sulfur dioxide control in particular?**

A The utility industry has not given a high priority to research and development (R & D), but will be required to spend considerably more on R & D in the future. For the past decade, electric utilities have been supporting R & D at a level estimated to be equivalent to approximately 0.25 percent of gross electrical revenues. In 1971, the utility industry reportedly spent $99 million for R & D. Approximately $40 million was spent for air pollution control, of which at least $23 million was allocated for the control of SO_2 emissions.

The Electric Research Council Task Force on R & D estimated that R & D expenditures by utilities, manufacturers, and the Federal government will rise to $1.209 billion in 1977. Roughly 75 percent of the projected R & D will be for improved energy conversion, about 15 percent for transmission and distribution, and only 9 percent for environmental needs.

Q. **Have designers solved the principal difficulties experienced with lime/limestone systems?**

A The problems with existing systems can be grouped into process and materials problems. The process problems include scaling (formation of calcium salts on scrubber surfaces), and plugging of boiler passages, scrubbers, packing, demisters, and reheaters. Materials problems are mainly corrosion and erosion of principal equipment. Some materials problems are inherently connected with process problems. For instance, in some systems it has been difficult to control pH, so that the solution becomes highly acidic, causing considerable corrosion. Refinement of the process to the point that pH can be kept within the noncorrosive range will prevent much of the material damage. The continuing development of corrosion-resistant materials is diminishing the importance of acid corrosion.

Solutions to both materials and process problems have been found although all process parameters have not been

optimized. In spite of difficulties encountered with them, lime/limestone systems will probably be the primary scrubbing system used in the immediate future. For the longer term, regenerable systems producing marketable byproducts may predominate.

Q. How long does it take to design and install an FGD system?

A. Commercial units have generally taken less than 2 years to install but in the future may take somewhat longer if demands exceed the production capacities of vendors. A magnesium oxide scrubber at Boston Edison's Mystic Station took 21 months from issuance of contract to start-up. A lime scrubber installed at Mitsui Aluminum in Japan needed only 10 months from completion of specifications to completion of construction. A difficult retrofit of a limestone scrubber at Commonwealth Edison's Will County Station (Illinois) took just under 2 years from the time scrubbing was first considered to time of startup.

Q. How long is a boiler out of operation when a scrubber is being installed?

A. A period of 4 to 6 weeks is normally required to tie in a scrubber to a utility power boiler. In some cases, the period may be somewhat longer. Everything but the final connecting duct is completed; then the boiler is shut down and final duct connections are made as quickly as feasible.

Each boiler has a normal maintenance downtime of at least 2 weeks every 12 to 18 months. Maintenance downtime can be used to tie in the scrubber, holding the net boiler firing time loss to about 3 to 4 weeks.

Q. What kind of guarantees are offered by vendors of FGD systems?

A. In general, vendors will guarantee SO_2 removal under specified conditions agreed upon with the operator, and they will guarantee the mechanical parts of the system for 1 year. These conditions are consistent with guarantees offered on boilers, steam turbines, and other equipment purchased by the electric utility industry. Not only do they offer written guarantees, but these companies have reputations to uphold and expect to derive a significant portion of their revenue in the future from the installation of FGD systems.

Q. How much sludge is produced from lime/limestone systems?

A. Ten pounds of coal containing 3 percent sulfur will produce 2 to 3 pounds of sludge, excluding fly ash, assuming that the sludge contains 25 to 50 percent water.

Q. What can be done with the solid wastes from lime/limestone scrubbing processes?

A. Most of the presently operating lime/limestone systems dispose of sludge materials in ponds on the site. If sufficient land is available, the pond is designed to store wet sludge material over the lifetime of the power plant. When land is not available at a plant site, the solids can be dewatered with clarifiers, filters, or centrifuges and transported, as sludges, by barge, truck, train, or pipeline to a landfill site.

Chemical fixation processes are available that will relieve problems that can result from the nonsettling of some sludges, although the costs of such fixation are not well established at this time. Such processes generally involve pozzolanic (cementitious) chemical reactions with fly ash and an additive such as lime; these reactions lead to the formation of a dry, solid, chemically inert material that is acceptable for landfill purposes.

Q. What potential water pollution problems are associated with FGD systems?

A. Liquids in alkaline scrubbing systems contain dissolved and suspended salts, some of which are reducing compounds, i.e., they remove oxygen from the liquid. The resultant liquid has an appreciable chemical oxygen demand (COD) and is deleterious to aquatic plant and animal life if allowed to enter rivers, lakes, etc. In addition, ground water and watercourses could be contaminated by seepage from sludge ponds. The possibility of water pollution is more apparent with lime/limestone systems than with regenerable sodium and magnesium base systems. There is little potential water pollution from dry processes and from the catalytic oxidation process.

Q. How can ground water and watercourse contamination from lime/limestone sludge disposal ponds be prevented?

A. Water contamination can be prevented by operating lime/limestone wet scrubbing systems in a closed loop. Closed loop means that all liquor entering the pond is recycled to the scrubber circuit; no sludge liquid is released to any watercourse.

To avoid seepage of liquor through the walls and floors of the disposal ponds, a sealant such as clay, tar, or plastic can be used if necessary. Present information indicates that ponds tend to seal themselves as sludge builds up.

Q. Why can't we use nuclear power and eliminate the inconvenience of FGD systems?

A. There have been numerous delays in the siting and construction of nuclear plants. In addition, there are unresolved environmental problems involved in these operations. Although it is expected that nuclear plants eventually will replace fossil fuel plants, no resultant reduction in SO_2 emissions is expected until after the year 2000.

Q. Don't FGD systems intensify the fuel shortage?

A. FGD will, in fact, lessen the fuel crisis by enabling us to employ high-sulfur coals and thus to utilize more of our very large coal reserves while conserving oil and gas, which are in short supply. Furthermore, it is estimated that, because clean fuels are in short supply, FGD systems will have to be applied to some 50,000 megawatts of existing electric generator capacity if air quality standards are to be met by 1977.

Q. Have any power plants achieved particular success in operating an FGD system?

A. The lime scrubbing system at the Mitsui Aluminum plant in Omuta, Japan, has demonstrated an enviable record since it was first put into operation in March 1972. Other systems installed on oil-fired boilers in Sweden and Japan have been as successful, but the Mitsui system is significant inasmuch as it has been operated continuously for more than 1 year on a coal-fired unit. The Mitsui scrubber was designed by an American chemical engineering firm that markets the same process in the United States. It serves a 156-megawatt coal-fired installation that generates electricity for a primary aluminum plant and also sells electricity to a neighboring utility.

Q. **Can the Mitsui scrubbing system be used on U.S. power plants?**

A. The system is considered applicable to U.S. power plants for the following reasons:

1. The inlet SO_2 concentrations in the Mitsui scrubbing system are quite similar to those found in plants throughout the U.S.

2. Carbide sludge (calcium hydroxide) used at the Mitsui plant and various grades of U.S. lime react similarly in scrubbing systems.

3. The Mitsui plant operates with a nearly constant electrical output, but has been subjected to enough variations in demand and flue-gas SO_2 concentration to demonstrate that the scrubbing system can handle varying stack-gas volumes. The majority of the newer and larger U.S. power plants are not subjected to widely fluctuating loads.

4. Most future American applications of lime scrubbing systems should involve steam generators as large or larger than the 156-megawatt Mitsui installation. These can use multiple scrubbing units (modules). It does not appear than any modules with greater than about 150-megawatt capacity will be utilized.

5. Fly ash removal at the Mitsui plant is accomplished with a relatively efficient, previously existing electrostatic precipitator. Similar equipment already exists at many U.S. power plants.

6. The Mitsui calcium sulfite/calcium sulfate effluent bleed disposal system is designed to operate, and has operated, as a closed recycle loop between the scrubbers and the disposal ponds. The recycle liquor has been totally saturated with sulfate for extended periods of time (months) without the occurrence of significant scale build-up or other deposition in the scrubbers.

Q. Has the Mitsui type of flue gas desulfurization system been installed at any U.S. plants?

A. Similar systems are being installed at utility plants in two Pennsylvania locations. The first of these will be put into operation in late 1973 at the Philips station of the Duquesne Light Company.

SULFUR DIOXIDE STACK GAS CLEANING SYSTEMS INSTALLED AT OR ON ORDER FOR U.S. ELECTRIC GENERATING STATIONS

Plant	Process[a]	Capacity, MW	Start-up date	Fuel	% Sulfur in fuel
1. Kansas Power and Light Lawrence #4	L	125	12/68	Coal	3.5
2. Kansas Power and Light Lawrence #5	L	430	11/71	Coal	3.5
3. City of Key West Stock Island #1	L	37	10/72	Oil	2.8
4. Kansas City Power and Light Hawthorne #3	L	130	11/72	Coal	3.5
5. Kansas City Power and Light Hawthorne #4	L	130	8/72	Coal	3.5
6. Louisville Gas and Electric Paddy's Run #6	L	70	4/73	Coal	3.5
7. Commonwealth Edison Will County #1	L	175	2/72	Coal	3.5
8. Boston Edison, Mystic #6	M	150	4/72	Oil	2.5
9. Illinois Power, Wood River	C	100	10/72	Coal	3.3
10. Kansas City Power and Light La Cygne	L	820	5/73	Coal	5.3
11. Detroit Edison Company St. Clair #6	L	180	12/73	Coal	3.8
12. Arizona Public Service Cholla	L	115	4/73	Coal	1
13. Duquesne Light Company Philips	L	100	6/73	Coal	2
14. Northern States Power Company Sherburne Company #1	L	680	5/76	Coal	1.2
15. Northern States Power Company Sherburne Company #2	L	680	5/77	Coal	1.2
16. Nevada Power Company Reid Gardner #1	S	125	6/73	Coal	1
17. Nevada Power Company Reid Gardner #2	S	125	6/73	Coal	1
18. Nevada Power Company Reid Gardner #3	S	125	75	Coal	0.8
19. Philadelphia Electric Company Eddystone #1	M	120	6/73	Coal	2.5
20. Potomac Electric and Power Dickerson #3	M	100	7/73	Coal	3
21. TVA, Widow's Creek #8	L	550	5/75	Coal	3.7
22. N. Indiana Public Service Company D. H. Mitchell #11	S	115	7/74	Coal	3.5

SULFUR DIOXIDE STACK GAS CLEANING SYSTEMS INSTALLED AT OR ON ORDER FOR U.S. ELECTRIC GENERATING STATIONS (Continued)

Plant	Process[a]	Capacity, MW	Start-up date	Fuel	% Sulfur in fuel
23. S. California Edison and S. W. Utilities Mohave #1	L	160	73	Coal	0.5
24. S. California Edison and S. W. Utilities Mohave #2	L	160	74	Coal	0.5
25. Indiana and Michigan Electric Tanners Creek	D	150	74	-	-
26. Ohio Edison and Others Bruce Mansfield #1	L	880	75	Coal	4.3
27. Ohio Edison and Others Bruce Mansfield #2	L	880	76	Coal	4.3
28. Public Service of Indiana Gibson Company	L	650	76	Coal	1.5
29. Potomac Electric and Power Dickerson #4	L	850	76	Coal	2
30. Potomac Electric and Power Dickerson #5	L	850	77	Coal	2
31. Potomac Electric and Power Chalk Point #3	M	630	75	Oil	-
32. Potomac Electric and Power Chalk Point #4	M	630	76	Oil	-
33. S. California Edison and S. W. Utilities Navajo #1	L	750	3/76 to 3/77	Coal	0.8
34. S. California Edison and S. W. Utilities Navajo #2	L	750	3/76 to 3/77	Coal	0.8
35. S. California Edison and S. W. Utilities Navajo #3	L	750	3/76 to 3/77	Coal	0.8
36. Montana Power Company Colstrip #1	L	720	6/75	Coal	0.8
37. Montana Power Company Colstrip #2					

[a] L - Limestone/lime scrubbing.
M - MgO scrubbing
C - Catalytic oxidation.
S - Sodium-base scrubbing.
D - CuO adsorption, dry process.